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APPLICATION FOR PATENT

MODULAR ICP TORCH ASSEMBLY

Inventors: Albert R. DePetrillo;
Craig R. Heden; and
Robert M. McGuire.

FIELD OF THE INVENTION

The present invention generally relates to inductively coupled plasma ("ICP") torches and in particular, to a modular ICP torch assembly.

BACKGROUND OF THE INVENTION

ICP torches have a long history in semiconductor processing and spectrographic applications. Commonly used ICP torches, however, are not easy to disassemble, thereby making repair and maintenance of the torch difficult. This results in undesirable equipment down time that, in a manufacturing environment, can significantly reduce production volume and increase per unit costs. Further, different applications or processing requirements often require different ICP torch configurations, component dimensions, and/or component materials. Consequently, multiple ICP torches may be used in the manufacturing or a test environment, thereby increasing manufacturing and/or test costs. Still further, coolant tubes that are fused in ICP torches to their plasma chambers to cool them down are subject to cracking and consequently, leaking of the coolant into the plasma chambers.

OBJECTS AND SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide an ICP torch that is easily assembled and disassembled to minimize equipment down time.

Another object is to provide an ICP torch that is modular in design so that component parts can be mixed and matched to suit their application use.

Another object is to provide an ICP torch that includes a coolant mechanism that avoids contamination of the plasma chamber upon failure, and is easily replaced.

Still another object is to provide an ICP torch that is reliable, efficient, high performing, and cost effective.

These and additional objects are accomplished by the various aspects of the present invention, wherein briefly stated, one aspect is a modular ICP torch assembly comprising a tubular plasma chamber, a tubular jacket, and detachable connector units. The detachable connector units hold the tubular plasma chamber concentrically within the tubular jacket so as to define an annular chamber between the two, and provide a flow of coolant through the annular chamber to cool the outer surface of the tubular plasma chamber.

Another aspect is a modular ICP torch assembly comprising a tubular plasma chamber, a rear connector unit, and an inductive coupling member. The rear connector unit is positioned and detachably held at a rear end of the tubular plasma chamber to provide a flow of material into the tubular plasma chamber. The inductive coupling member is for inductively applying energy to the material flowing

through the tubular plasma chamber in order to produce and sustain plasma in the chamber.

Still another aspect is a modular inductively coupled plasma torch assembly. A rear connector unit is positioned and detachably held at a rear end of a tubular plasma chamber to provide a flow of material into it. Detachable connector units are positioned on opposite ends of a tubular jacket, and hold the tubular plasma chamber concentrically within the tubular jacket so as to define an annular chamber between the two tubes. An inductor coil is disposed concentrically around the tubular jacket and energized so as to generate plasma from the material flowing in the tubular plasma chamber. To cool the tubular plasma chamber, coolant flows through the annular chamber using inlet and outlet ports in the detachable connector units for such flow of coolant.

Additional objects, features and advantages of the various aspects of the present invention will become apparent from the following description of its preferred embodiment, which description should be taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a side view of a modular ICP torch assembly utilizing aspects of the present invention.

FIG. 2 illustrates a top view of a detachable rear connector unit included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 3 illustrates a top view of a detachable front connector unit included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 4 illustrates a side view of a detachable front connector unit included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 5 illustrates a side view of a detachable jacket connector unit included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 6 illustrates a front view of a cinch nut included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 7 illustrates a side view of a cinch nut included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 8 illustrates a front view of a seal ring included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 9 illustrates a side view of a seal ring included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 10 illustrates a cross-sectional view of one end of a detachable connector, utilizing aspects of the present invention.

FIG. 11 illustrates a side view of an alternative modular ICP torch assembly utilizing aspects of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 illustrates a side view of a modular ICP torch assembly **100** including a tubular plasma chamber **101,** a tubular jacket **102** that is disposed concentrically around the tubular plasma chamber **101,** and an inductor coil **103** that is disposed concentrically around the tubular jacket **102.** The induction coil **103** preferably has a coil diameter that is slightly larger than the outer diameter of the tubular jacket **102** so that the tubular jacket **102** can fit comfortably, yet snugly in the induction coil **103.** On the other hand, the tubular jacket **102** preferably has an inner diameter that is significantly larger than the outer diameter of the tubular plasma chamber **101** so that an annular chamber sufficient in size to accommodate desired coolant volume flow rate is defined between the inner surface of the tubular jacket **102** and the outer surface of the tubular plasma chamber **101.**

In operation, the inductor coil **103** is energized while source material commonly in gaseous form flows by the induced field to generate plasma in the tubular plasma chamber **101.** The composition and form of such material are chosen according to the application of the ICP torch assembly **100.** Although an inductor coil is shown in this example for inductively applying energy to the source material, other means for doing so are also contemplated to be within the scope of the present invention. Additional details on the operation of and application examples for an ICP torch are described in commonly owned United States Patent Application Serial Number 10/404,216 entitled "Remote ICP Torch for Semiconductor Processing," which is incorporated herein by this reference.

Since the generation of plasma in the tubular plasma chamber **101** causes the tubular plasma chamber **101** to heat up, coolant is passed through the annular chamber defined between the concentrically aligned tubular plasma chamber **101** and tubular jacket **102** to cool the outer surface of the tubular plasma chamber **101**. The coolant may be in gaseous or liquid form, and may flow at various flow rates according to the application of the ICP torch assembly **100**. As an example, deionized water is a commonly used coolant in ICP torch applications.

Also included in the modular ICP torch assembly **100** are several detachable connector units. These units serve to not only hold the various components of the modular ICP torch assembly **100** together, but they also provide inlet ports for source material to flow into the tubular plasma chamber **101**, and inlet and outlet ports for the coolant to flow into and out of the annular chamber defined between the tubular jacket **102** and the tubular plasma chamber **101**. Note that **FIG. 1** only shows simplified versions of these detachable connector units. Therefore, **FIGS. 2~10** are provided for a better understanding of their construction, assembly and operation.

A detachable rear connector unit includes a rear connector **201** whose top view is shown in detail in **FIG. 2**. As shown in more detail in **FIG. 10**, the rear connector **201** has an open end **211** through which a rear end of the tubular plasma chamber **101** is positioned and held in place by a cinch nut **203**, a seal ring **204**, a compressible O-ring **205**, and slip washer ring **206**. The cinch nut **203** is shown in more detail for front and side views respectively in **FIGS. 6** and **7**, and the seal ring **204** is shown in more detail for

front and side views respectively in **FIGS. 8** and **9.** The O-ring **205** and the slip washer ring **206** are simply well known "O" shaped components and therefore, are not separately shown in detail.

The cinch nut **203**, the slip washer ring **206**, the seal ring **204**, and the O-ring **205** are each placed in that order around the tubular plasma chamber **101**, and slided down part way along its outer surface to get temporarily out of the way. The tubular plasma chamber **101** is then inserted into the open end **211** of the rear connector **201** until it nears or stops against an annular rear wall **223** of an outer cylindrical cavity **214** of the rear connector **201**. The diameter of the outer cylindrical cavity **214** is preferably approximately the same as that of the tubular plasma chamber **101** so that the tubular plasma chamber **101** fits snugly in the outer cylindrical cavity **214** with minimal lateral movement when inserted therein. The O-ring **205** is then slided back down the outer surface of the tubular plasma chamber **101** until it stops against a tapered wall **212** of the rear connector **201**. Likewise, the seal ring **204**, slip washer ring **206**, and cinch nut **203** are also slided back down along the outer surface of the tubular plasma chamber **101** until inner threads **604** of the cinch nut **203** engage outer threads **213** of the rear connector **201**.

The cinch nut **203** is then screwed into the outer threading of the connector **201** so the seal ring **204** is pushed into compressing the O-ring **205** against the tapered wall **212** of the rear connector **201**, thereby generating compression forces within the thus compressed O-ring **205** that radiate outward from the O-ring **205** and against the seal ring **204**, the tapered wall **212**, and the outer surface

of the tubular plasma chamber **101**, so as to securely hold the rear connector **201** in place against the tubular plasma chamber **101**. The slip washer ring **206** placed between the seal ring **204** and the cinch nut **203** serves to inhibit torque applied to the cinch nut **203** (e.g., for screwing it into the outer threading **213** of the rear connector **201**) from being transferred to the O-ring **205**.

The rear connector **201** also has two inlet ports **202** and **220** for receiving material flows from external material sources and providing the material flows into the tubular plasma chamber **101**. The inlet ports **202** and **220** utilize compression type fittings in order to accommodate hoses connected at opposite ends to the external material sources. The materials provided at inlet ports **202** and **220** may be different materials or the same material according to the application of the modular ICP torch **100**. Materials entering through inlet ports **202** and **220** first enter an inner cylindrical cavity **215** before exiting through a circular opening **224** into the interior of the tubular plasma chamber **101** which is positioned in the outer cylindrical cavity **214** through open end **211** of the rear connector **201**. The width of the annular wall **223** used as a stop for the tubular plasma chamber **101** is determined by the difference in diameters of the circular opening 224 and the outer cylindrical cavity **214**.

A sapphire window **225** prevents the flows of materials from exiting the inner cavity **215** through an opening **221** included in the back of the rear connector **201**. The internally threaded opening **221** is included in the back of the rear connector **201** so that an optical emission spectrometer or other metrology system may be attached to

the modular ICP torch **100**. The optical emission spectrometer views the plasma generated in the tubular plasma chamber **101** in this case through the sapphire window **225**.

A detachable front connector unit includes a front connector **301** whose top view is shown in detail in **FIG. 3** and side view shown in detail in **FIG. 4**. The front connector **301** has a first open end **314** adapted to receive a front end of the tubular plasma chamber **101**, and a second open end **320** adapted to receive tubing **104** that is fludically coupled, for example, to a processing chamber for processing at least one semiconductor wafer. The tubular plasma chamber **101** is positioned and held in place with respect to the front connector **301** by a cinch nut **303**, a seal ring **304**, a compressible O-ring **305**, and slip washer ring (not shown), in much the same manner as described in reference to their counterparts in the rear connector unit as previously described. Likewise, the tubing **104** is positioned and held in place with respect to the front connector **301** by a cinch nut **306**, a seal ring **307**, a compressible O-ring **308**, and slip washer ring (not shown), also in much the same manner as described in reference to their counterparts in the rear connector unit as previously described.

A first cylindrical cavity **317** in the front connector **301** receives the tubular plasma chamber **101** through the first open end **314**, and a second cylindrical cavity **319** receives the tubing **104** through the second open end **320**. An inner cylindrical cavity **318** fluidically couples the first and second cylindrical cavities **317** and **319** so that plasma generated material flowing into the

first open end **314** passes out of the second open end **320**. The diameter of the first cylindrical cavity **314** is preferably approximately the same as that of the tubular plasma chamber **101** so that the tubular plasma chamber **101** fits snugly in the first cylindrical cavity **314** with minimal lateral movement when inserted therein. The diameter of the first cylindrical cavity **314** is also preferably larger than that of the inner cylindrical cavity **318** by an amount sufficient to define an annular wall at the rear of the first cylindrical cavity **317** that serves as a stop for the tubular plasma chamber **101**, as well as providing sufficient thickness to accommodate flared inlet channels **312** and **322**. The second cylindrical cavity **319** is also larger than the diameter of the inner cylindrical cavity **318** by an amount sufficient to define an annular wall at the rear of the second cylindrical cavity **319** that serves as a stop for the tubing **104**. The diameter of the second cylindrical cavity **319** is smaller than that of the first cylindrical cavity **317** in this example so as to increase the flow rate of plasma generated material going into the tubing **104**.

The front connector **301** has two inlet ports **302** and **313** adapted, for example, for compression fittings or other hose coupling mechanism for receiving material flows from external material sources and directing the material flows into the tubular plasma chamber **101** through flared inlet channels **312** and **322** so as to flow back towards, and in some applications be part of, the generation of plasma in the tubular plasma chamber **101**. The inlet channels **312** and **322** are flared so that their material flows are at angles from the axis of the tubular plasma chamber **101**,

thus resulting in good material distribution in the tubular plasma chamber **101**.

Those familiar with the art of ICP torches will appreciate that in addition to the embodiments described herein, other front connector designs may also be used in practicing the present invention, including, for example, those that directly bolt the tubular plasma chamber **101** to a processing chamber such as used for processing at least one semiconductor wafer.

In applications where material flow through the front connector unit is not necessary, a modified version of the front connector **301** may be employed. In the modified version, inlet ports **302** and **313** and their corresponding flared inlet channels **312** and **322** are eliminated. Construction of the first and second open ends **314** and **320** and their corresponding cylindrical cavities **317** and **319** remain the same, so that the same tubular plasma chamber **101**, tubing **104**, cinch nuts **303** and **306**, seal rings **304** and **307**, O-rings **305** and **308**, and slip washer rings can be used with the modified version of the front connector unit. Consequently, easy conversion from one version of the modular ICP torch assembly to another is facilitated as applications for the modular ICP torch assembly change.

In applications where cooling of the tubular plasma chamber **101** is not required, then the modular ICP torch assembly **100** is assembled by first inserting the tubular plasma chamber **101** into the induction coil **103**, then attaching the rear and front connector units, in either order, as described above. The tubular jacket **102** and corresponding pair of connection units for attaching

the tubular jacket **102** to the tubular plasma chamber **101** are not included in the assembly.

In applications where cooling of the tubular plasma chamber **101** is required, however, then the module ICP torch assembly **100** is assembled by inserting the tubular plasma chamber **101** into the tubular jacket **102**, inserting the tubular jacket **102** into the induction coil **103**, attaching a pair of connection units at opposing ends of the tubular jacket **102** so as to attach the tubular jacket **102** to the tubular plasma chamber **101**, and attaching the rear and front connector units to the ends of the tubular plasma chamber **101** as described above.

The pair of connection units that attach the tubular jacket **102** to the tubular plasma chamber **101** are referred to as detachable first and second connection units. The detachable first connection unit includes a first connector **401** whose side view is shown in detail in **FIG. 5.** It has a large diameter end **417** through which the tubular jacket **102** is inserted and held in a large cylindrical cavity **420**, and a small diameter end **411** through which the tubular plasma chamber **101** passes through so as to fill up a small cylindrical cavity **414.** The diameter of the large cylindrical cavity **420** is approximately the same as that of the tubular jacket **102** so that the tubular jacket **102** fits snugly in the large cylindrical cavity **420** with minimal lateral movement when inserted therein. Likewise, the diameter of the small cylindrical cavity **414** is approximately the same as that of the tubular plasma chamber **101** so that the tubular plasma chamber **101** fits snugly in the small cylindrical cavity **414** with minimal lateral movement when inserted therein.

To assemble the first connection unit, a cinch nut **403**, a slip washer ring (not shown), a seal ring **407**, and a compressible O-ring **405** are each placed in that order around the tubular jacket **102**, and slided part way down its surface to get temporarily out of the way. The tubular jacket **102** is then inserted into the large diameter end **417** of the first connector **401** until it stops against an annular rear wall **421** of the large cylindrical cavity **420**. The O-ring **405** is then slided back down the outer surface of the tubular jacket **102** until it nears or stops against a tapered wall **419** of the large diameter end **417** of the first connector **401**. Likewise, the seal ring **407**, slip washer ring (not shown), and cinch nut **403** are also slided back down along the outer surface of the tubular jacket **102** until inner threads of the cinch nut **403** engage outer threads **418** of the first connector **401**.

The cinch nut **403** is then screwed into the outer threading of the first connector **401** so that the seal ring **407** is pushed in compressing the O-ring **405** against the tapered wall **419** of the first connector **401**, thereby generating compression forces within the thus compressed O-ring **405** that radiate outward from the O-ring **405** and against the seal ring **407**, the tapered wall **419**, and the outer surface of the tubular jacket **102**.

A compressible O-ring **406**, a seal ring **408**, a slip washer ring (not shown), and a cinch nut **404** are each placed in that order around the exposed rear end of the tubular plasma chamber **101**, and slided down its surface towards the small diameter end **411** of the first connector **401** until the O-ring **406** nears or stops against a tapered wall **413** of the small diameter end **411** of the first

connector **401**. The cinch nut **404** is then screwed into the outer threading **412** of the first connector **401** so the seal ring **408** is pushed into compressing the O-ring **406** against the tapered wall **412**, thereby generating compression forces within the thus compressed O-ring **406** that radiate outward from the O-ring **406** and against the seal ring **408**, the tapered wall **412**, and the outer surface of the tubular plasma chamber **101**, so as to securely hold the first connector **401** against the tubular jacket **102** on one end and the tubular plasma chamber **101** on the other end of the first connector **401**.

The cinch nut **404**, seal ring **408**, O-ring **406**, and corresponding slip washer ring are identically sized and constructed as their respective counterparts as described in reference to **FIGS. 1**, **2**, and **6~9**. The cinch nut **403**, seal ring **407**, O-ring **405**, and corresponding slip washer ring, on the other hand, are each shaped as, but larger their respective counterparts as described in reference to **FIGS. 1**, **2**, and **6~9**, since these components are adapted for the larger diameter of the tubular jacket **102**.

The detachable second connector unit is similarly constructed as the first detachable connector unit, and attached at the opposite end of the tubular jacket **102** to the tubular plasma chamber **101** in the same manner as described in reference to the first detachable connector unit. After attaching both ends of the tubular jacket **102** to the tubular plasma chamber **101**, the detachable rear and front connector units are then attached to the tubular plasma chamber 101 as previously described.

As previously explained, coolant for cooling the tubular plasma chamber **101** is passed over the outer surface

of tubular plasma chamber **101** through the annular chamber defined between the concentrically aligned tubular jacket **102** and tubular plasma chamber **101**. The coolant, which is provided from an external coolant source, enters an inlet port **402** in the first connector **401** of the detachable first connector unit, flows through an opening **416** of the first connector **401** into the annular chamber, exits the annular chamber on the opposite side of the tubular jacket **102** though an opening in a second connector **501** of the detachable second connector unit, and returns to the external coolant source through an outlet port **502** of the second connector **501**. Although the port **402** is referred to as an inlet port and the port **502** is referred to as an outlet port in this example, it is to be appreciated that if the coolant were to flow in the opposite direction, then the port **502** would serve as an inlet port and the port **402** would serve as an outlet port in that case. Therefore, the ports **402** and **502** are referred to as respectively being inlet and outlet ports for convenience only and such terminology should not be used to place any limitation on their actual or claimed use.

When the pressure created by the flow of coolant becomes very large, it may be advantageous to provide additional support to hold the tubular jacket **102** in place. **FIG. 11** illustrates a top view of a second embodiment of a modular ICP torch assembly wherein a supporting rod **903** helps hold the tubular jacket **102** in place by supporting the first and second connectors from being forced apart by the coolant pressure. The supporting rod **903** has threaded ends which are inserted into mechanical supports **901** and **902** respectively integrated on the first and second

connectors **401** and **501**. Nuts **904** and **905** screwed into the threaded ends of the supporting rod **903** then hold the supporting rod **903** in place between the mechanical supports **901** and **902** to prevent the first and second connectors **401** and **501** from being forced apart due to the large coolant pressure. For additional and balanced support, a second supporting rod may be installed in the same manner on an opposite side of the modular ICP torch assembly.

Although the various aspects of the present invention have been described with respect to a preferred embodiment, it will be understood that the invention is entitled to full protection within the full scope of the appended claims.